LATE OTIRAN AND EARLY ARANUIAN RADIOCARBON DATES FROM SOUTH ISLAND LOCALITIES

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ABSTRACT

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Thirteen radiocarbon dates and their stratigraphic settings are reported:

(1) Three for events during the Larrikins ice advance, the penultimate stadial of the Otira Glaciation in the Taramakau Valley, Westland (18,450 ± 300 yr B.P., 17,250 ± 250 yr B.P. and 16,600 ± 200 yr B.P.). The last date may be erroneous through contamination with young carbon;

(2) Five for phases of sedimentation in the early Aranuian Interglacial in the Lewis-Boyle River Valleys, North Canterbury (13,050 ± 200 yr B.P., 12,800 ± 200 yr B.P., 11,700 ± 200 yr B.P., 10,900 ± 200 yr B.P., 10,800 ± 150 yr B.P.). The last date is probably erroneous through contamination with young carbon;

(3) Four for deglaciation in the Rakaia and Rangitata Valleys, Central Canterbury. One date from the Acheron Valley in the Rakaia, (11,650 ± 200 yr B.P.) is probably erroneous through contamination with young carbon. One date from the locality Craig Phillips in the Rangitata (11,450 ± 350 yr B.P.) is a minimal age for recession of ice at the end of the last Otiran stadial, but thought not to be a close estimate of the true age of ice recession. The remaining two dates (9,480 yr B.P. from the Rakaia and 9,730 ± 190 yr B.P. from the Rangitata) are minimal ages for recession from early Aranuian glacial readvances in those valleys. Along with other evidence, they show that there was substantial glacial expansion there between about 11,900 and 10,000 yr B.P;

(4) One date (11,300 ± 200 yr B.P.) provides a minimal age for deglaciation of Takahe Valley, Te Anau, Fiordland.

KEYWORDS: radiocarbon dates - Otira Glaciation - Aranui Interglacial - till - stadial - deglaciation - readvance.

INTRODUCTION

This paper reports thirteen radiocarbon dates and their stratigraphic settings and significance for some sites in Westland, Canterbury and Fiordland (Fig. 1). Three dates from the type area for the Larrikins and Loopline Formations, near Kumara, Westland (Suggate 1985), record phases of the Larrikins glacial advance which is recognized as the penultimate stadial of the Otira Glaciation in this locality.

The rest of the dates help the interpretation of the climate and geomorphology of the early Aranuian Interglacial. Eight dates are for sediments deposited after the recession of the glaciers of the final stadial of the Otira Glaciation. They are from sites in the Lewis and Boyle Rivers, North Canterbury; the Rakaia and Rangitata Valleys, Central Canterbury and Takahe Valley, Te Anau, Fiordland. Two dates from the upper Rakaia and upper Rangitata Valleys, Canterbury, provide minimal ages for the recession of glaciers which had readvanced in the upper valleys early in the Aranuian period. They were briefly reported in Burrows & Gellatly (1982).

THE RADIOCARBON DATE LIST

The dates to be considered are listed in Table 1, together with brief details about the sites, materials dated, stratigraphic positions and significance. The stratigraphy and interpretation of significance are outlined more fully in the next section.

In the list, the dates are given according to the half-life 5,568 years (Old T½) and the half-life 5,730 years (New T½). The Old T½ dates ('radiocarbon years') are cited, thereafter, in the text.

SITE DESCRIPTIONS, INTERPRETATION AND SIGNIFICANCE OF DATES

OTIRAN SITES

Larrikins Formation, Taramakau Valley, Westland

1. Kapitea Reservoir Road, near Dillmanstown. The site (Figs. 2 & 3) was exposed in a terrace

Laboratory number	Radiocarbon date (yr B.P.) Old T ½	New T ½	Locality, grid reference and altitude	Material dated	Stratigraphic position	Significance	Collector, reference, etc.
N.Z.-4408	18,450±300	18,950±300	East side of Kapitea Reservoir Rd., Dillmanstown, Westland. J32/620368 134 m	peaty silt	Bottom of peaty silt layer resting on slightly weathered till, buried by 3 m of till.	Minimal age for beginning of an ice-free interval at the site. Marks beginning of organic sedimentation.	Collectors C.J.Burrows, R.P.Suggate, N.T.Moar. Moar (1980) Suggate (1965, 1985) Burrows (1984).
N.Z.-4407	17,250±250	17,750±250	same site as above	peaty silt with twigs	Slightly disturbed top layer of peat, as above.	Age for the end of organic sedimentation and buried by glacial readvance over the site.	as above
N.Z.-7517	16,600±200	17,100±210	South side of canal near bridge on Loopline Rd., near Okuku Reservoir,	peaty silt with moss	From peaty silt layer resting on till, buried by more than 2 m of till.	Age for peaty soil formed during an ice-free interval at the site, predating a renewed episode of glacial depsoition which buried the deposit. May be too young.	Collector C.J. Burrows. Suggate (1965, 1985).
N.Z.-6092	13,050±200	13,450±200	West side of Lewis River, upstream of Boyle River confluence, North Canterbury. M32/588547 580 m	peat	Thin peat layer underlain by silt, sand and peat layers, overlain by pebble-cobble alluvium.	Organic sedimentation during cool conditions.	Collector C.J. Burrows.
N.Z.-6093	12,800±200	13,150±200	same site as above	peat	Thin peat layer underlain by compact silt and till-like gravel over bedrock, overlain by silt, sand and peat layers.	as above	Collector C.J. Burrows.

Table 1. Late Otiran and early Aranuian radiocarbon dates from South Island localities. (*Continued on following pages.*)

Laboratory number	Radiocarbon date (yr B.P.) Old T ½	New T ½	Locality, grid reference and altitude	Material dated	Stratigraphic position	Significance	Collector, reference, etc.
N.Z.-6091	11,700±200	12,050±200	same site as above 581 m	peat	Bottom of peat layer between sheets of alluvium.	Minimal age for for beginning of stable period between two periods of aggradation. Beginning of organic sedimentation.	Collector C.J. Burrows.
N.Z.-3904	10,900±200	11,250±200	same site as above	peat	Top of peat layer between sheets of alluvium.	Age close to the end of a stable period between two episodes of aggradation.	Collector C.J. Burrows
N.Z.-6180	10,800±150	11,100±500	West side of Boyle River, 200 m upstream of Doubtful River confluence, North Canterbury. M32/562511 548 m	wood	Thin organically rich layer in unevenly-bedded sand, silt and organic layer presumed to be lake bottom-set beds. 8 m above present river level, 6 m below top of deposit, which is overlain by 1.5 m of alluvium.	Age of the particular horizon in lake sediments, but may be too young.	Collector C.J. Burrows. Clayton (1968).
N.Z.-1290	11,650±200	11,990±200	North bank of lower Acheron River, Rakaia Valley, near Lake Coleridge Road bridge, Central Canterbury. K35/956555 380 m	wood	Thin organically rich layer in laminated sands and silts above till, below alluvium. About 7 m above till, 10 m below top of exposure, which grades into fine alluvium.	Age of the particular horizon in lake sediments, but may be too young.	Collectors C.J. Burrows, N.T. Moar.
N.Z.-6288	11,450±350	11,800±350	Kettlehole in moraine south-east of roche moutonee Craig Phillips, Rangitata Valley, near Mt Potts Station, Central Canterbury. J36/3399374 533 m	silty fine organic mud	Bottom of sediment column in bog (980-990 cm below surface of mire). Rests on stones.	Minimal age for recession of ice from the final stadial of the Otira Glaciation in this area, but may not be close to the true age for ice recession.	Collector C.J. Burrows, G. Young. Mabin (1980).

Table 1. *(Continued from previous page.)*

Laboratory number	Radiocarbon date (yr B.P.) Old T ½	New T ½	Locality, grid reference and altitude	Material dated	Stratigraphic position	Significance	Collector, reference, etc.
N.Z.-4772	9,730±190	10,000±250	Sinclair Plateau, Clyde River, Rangitata Valley, Central Canterbury. J35/316537 990 m	organic lake mud	Bottom of sediment column in bog beside tarn (280-300 cm below surface of mire). Rests on till.	Minimal age for recession of Clyde Glacier after readvance to 10 km beyond present terminal position of glacier.	Collector C.J. Burrows. Burrows & Gellatly (1982).
N.Z.-4484	9,480±130	9,760±140	Summit of Meins Knob, near Lyell Glacier, Rakaia Valley, Central Canterbury. J35/413663 1220 m	compressed peat	Bottom of sediment column in peat bog (132-134 cm below surface of mire). Rests on till.	Minimal age for recession of Lyell Glacier which overtopped Meins Knob and deposited drift in lower Reischek Valley at least 5.5 km beyond present terminal position of glacier.	Collector, C.J. Burrows Burrows & Russell (1975) Burrows & Gellatly (1982).
N.Z.-5530	11,300±200	11,600±200	West of Lake Orbell on south-east side of Takahe Valley, Te Anau, Fiordland. D42/912328 900 m	peat	Bottom of sediment column in sloping peat bog (395-400 cm below surface of mire). Resting on stones.	Minimal age for deglaciation of Takahe Valley. Beginning of organic sedimentation.	Collector C.J. Burrows.

Table 1. *(Continued from previous page.)*

road cut in 1976, during preparation of the new Kapitea Reservoir. Vegetation, soil and till overlying the dated soil layer were scraped off, so that the full depth from the surface to the dated soil layer is not known. It was probably more than than 3 m, judged by the positions of nearby undisturbed surfaces.

Samples were taken from the top and bottom of a layer of peaty silt containing leaves and small twigs. This buried soil layer (discontinuous organic lenses, alternating with inorganic silty layers of variable thickness) occurred on both sides of the road cut. It was sampled on the east side, where it was exposed over more than 50 m horizontal distance.

The dates (± twice the error), do not overlap, so the interval between beginning and end of peat deposition is assumed to be about 1,000 years.

The macroflora recovered from the peaty silt consists of:

Cyathodes fraseri leaves
Euphrasia sp. cf *disperma* leaves
Hebe odora leaves
cf *Montia fontana* seeds
Myrsine nummularia leaves
Polytrichum cf *alpinum* leaves
P. juniperinum leaves
Other mosses.

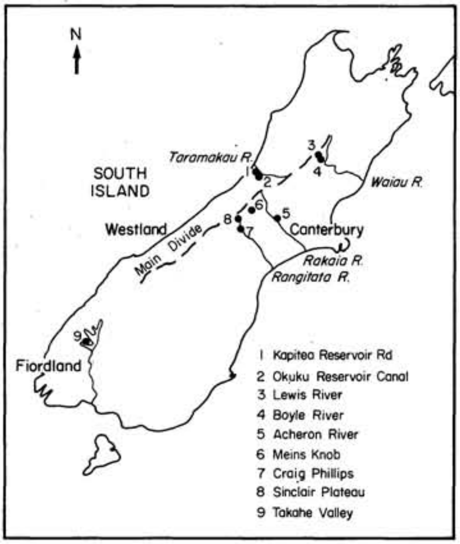

Figure 1. Location map for the sites described in the text.

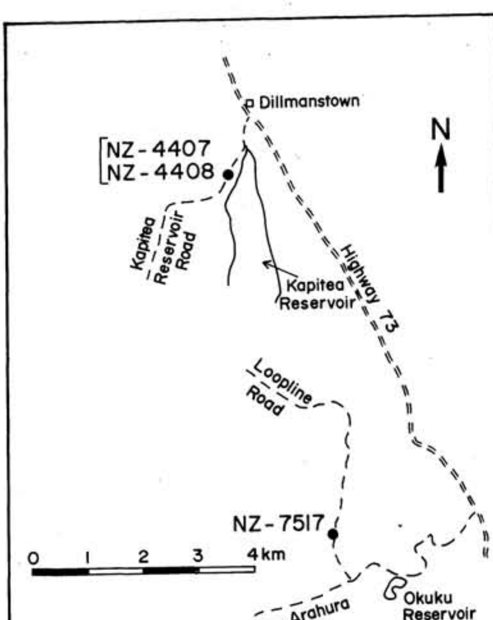

Figure 2. Location map for the Larrikins Formation sites. See Table 1 for the dates and further site details relevant to each figure.

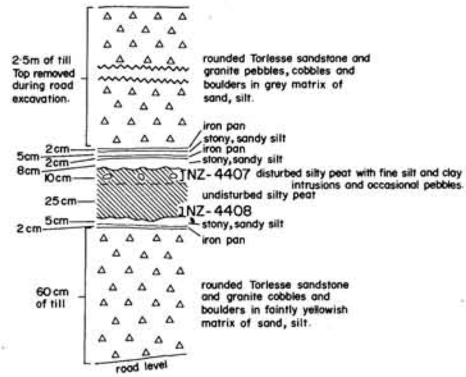

Figure 3. Diagram of section at the Kapitea Reservoir Road site (east side of road).

Pollen analysis by N. T. Moar (1980) revealed dominant Poaceae and abundant Asteraceae, *Coprosma*, *Hebe*, as well as *Cyperaceae*, *Plantago*, *Lycopodium fastigiatum* and various other herbaceous species in small amounts.

Hebe is the only taxon common to both pollen and macrofossil assemblages. A few *Nothofagus menziesii*, *Metrosideros, Phyllocladus* and *Halocarpus* pollen grains were found, presumably derived from sites some distance away.

The assemblage of plants represented by macrofossils and abundant microfossils is more like those of present subalpine wet sites (as on the summit of Arthurs Pass) than lowland wet sites, except that *Euphrasia disperma* is usually found in lowland pakihi now. The till sheet under the dated soil, according to R. P. Suggate (pers. comm.), is only faintly weathered, and soil development is weak.

The buried soil layer could represent only a brief episode of freedom from ice coverage along the fluctuating ice margin, rather than a full interstadial.

2. *Loopline Road, near Okuku Reservior.* During construction work for a canal near the Okuku Reservoir in 1978, discontinuous, disturbed organic layers, representing a soil overridden by ice and buried by till, were exposed in the canal wall near the bridge where Loopline

Road crosses it (Figs. 2 & 4). Disturbance of the soil layer was presumably contemporaneous with the emplacement of the till. At least 2 m thickness of till, as well as the modern soil and vegetation, had been scraped off above the buried soil during excavation of the canal.

The dated soil may have been buried by the glacial episode which also buried the soil at the Kapitea Reservoir, in which case the age, (16,600 ± 200 yr B.P., N.Z.-7517) taken at face value, seems too young, possibly because the sample is contaminated with young carbon. Alternatively the date may represent a slightly later phase of the Larrikins glacial advance because its age overlaps with that of N.Z.-4407 (± twice the error). R. P. Suggate (pers. comm.) has suggested that the final stadial of the Otira Glaciation in this area, the Moana advance, which left moraines lower in the Taramakau Valley (Suggate 1965), occurred about 16,000-14,000 years ago. The final word on more precise dating of the Westland late Otiran glacial chronology must await the recovery of further dateable material in unequivocal situations.

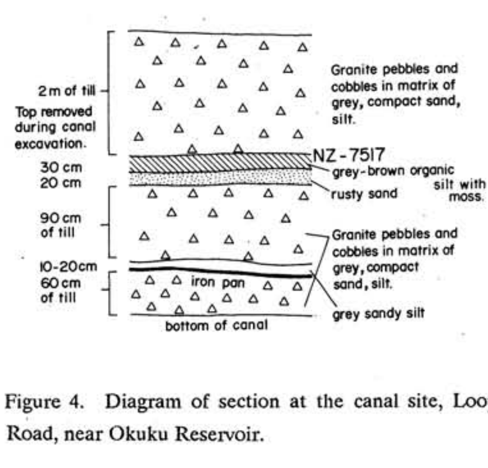

Figure 4. Diagram of section at the canal site, Loopline Road, near Okuku Reservoir.

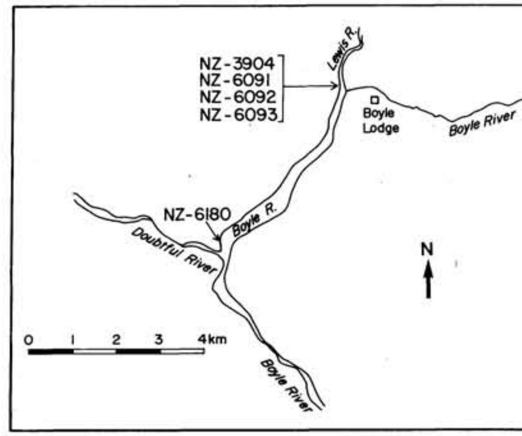

Figure 5. Location map for the Lewis River - Boyle River sites.

EARLY ARANUIAN SITES

Lewis-Boyle Rivers, North Canterbury

1. Lewis River. Several peaty layers are exposed in a section cut by bank erosion by the Lewis River on its west side, opposite its confluence with the Boyle River (Figs. 5 & 6). The lowermost peaty layers are thin (1-2 cm). They occur in sloping silt and sand layers, which overlie a till-like diamicton, above bedrock. There is overlap in the respective dates for the lowest and highest of the peaty layers (N.Z.-6093, 12,800 ± 200 yr B.P.; N.Z.-6092, 13,050 ± 200 yr B.P.) ± one times the error. The deposits containing the peaty layers are assumed to have been laid down rapidly, about 13,000 years ago, possibly as a slope deposit, under cool conditions. The Lewis Valley is thought not to have been occupied by a glacier during the final Otiran stadial (Clayton 1968). However cirque glaciers were almost certainly present on the mountains overlooking the valley at that time.

Two further dates, N.Z.-6091, 11,700 ± 200 yr B.P. and N.Z. -3904, 10,900 ± 200 yr B.P., from about 2 m higher in the same section, are for the bottom and top, respectively, of a prominent, 35 cm thick peat layer lying horizontally between two alluvial deposits (Fig. 6). These dates (± twice the error) do not quite overlap, so the interval between beginning and end of peat deposition is assumed to be about 800 years. The time from 11,700 ± 200 to 10,900 ± 200 years ago is interpreted as a locally stable period which was preceded by and ended by extensive fluvial deposition. The gravel (up to 5 m thickness) above the peat layer contains a more-or-less horizontal buried soil. The gravel was deposited by a stream issuing from a high valley overhanging the site. The causes of the depositional episodes giving rise to the upper gravel

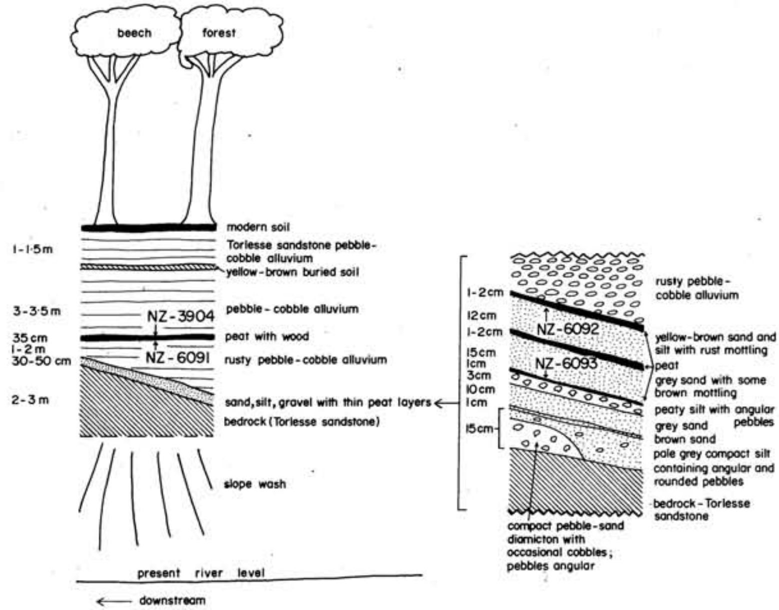

Figure 6. Diagram of section at the Lewis River site. At left, the full section; on right, enlarged view of the lower, sloping sand, silt and gravel bed with thin peat layers.

sheets cannot be ascertained from available evidence.

2. *Boyle River-Doubtful River Confluence*. The site (Figs. 5 & 7), (a section cut in bottom-set deltaic beds of a former lake by river erosion) was described by Clayton (1968). It consists of more or less horizontal, but irregularly-bedded sands and silts containing thin layers rich in plant remains, including small branches. The date N.Z.-6180, 10,800 ± 150 yr B.P. was obtained for a piece of wood from a layer 8 m above the present river level. Clayton (1968) obtained a date K1-354-1, 13,309 ± 203 yr B.P. on wood from near the same position.

There are problems with the interpretation of N.Z.-6180 in relation to K1-354-1. Firstly Clayton's material, processed by a different laboratory, may be subject to systematic difference arising from the use of different standards, laboratory procedures and equipment. However such differences would probably be less than 1,000 years if the wood samples contained the same proportions of radiocarbon. Secondly (and most likely) the N.Z.-6180 sample may have been contaminated with young carbon. A third, less likely, option is that the dates do actually reflect an age difference of about 2,500 years for horizons not far apart. Further field investigation and check-dating is warranted.

Clayton (1968) proposed that the deltaic lacustrine deposits in the lower Boyle Valley (the bottom-set beds mentioned here and extensive fore-set beds further up-valley) result from damming of the ancient Boyle River further east by a glacier extending from the Hope River Valley across the lower Boyle Valley. Clayton suggested that the K1-354-1 date represented the delayed melting of stagnant, final stadial Otiran ice. An alternative interpretation is that a rock bar, landslide, or moraine, rather than glacier ice, dammed the lake and that the dam was not breached until well after ice from the last Otiran stadial in the area had melted away. Although one other date associated with glacial deposits (N.Z.-531, 13,400 ± 150 yr B.P., from Paringa, South Westland, Suggate 1968) suggests that Otiran glaciers were still retreating from their final stadial in the mid 14th millenium B.P., other dates indicate recession from the last Otiran glacial advance at least as early as the beginning of the 15th millenium B.P. (cf Burrows 1983).

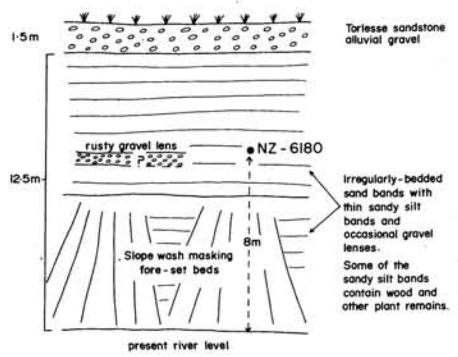

Figure 7. Diagram of section at the Boyle River-Doubtful River confluence.

Rakaia River Valley, Central Canterbury

1. Lower Acheron Valley. In the lower Acheron Valley, 5 km east of the Lake Coleridge Power Station, a steep bank of laminated sand and silt grading upward into fine alluvial gravel was exposed in 1967 (Figs. 8 & 9). The site has subsequently been overgrown by scrub. In 1967 very thin, discontinuous organic layers were evident in places among the laminations. The dated sample (N.Z.-1290, 11,650 ± 200 yr B.P.) occurred in one of these.

The sediments at the site resemble those of proglacial lakes. The presence of till some 7 m lower than the dated horizon also suggests the proximity of ice. The final (Acheron) stadial of the Otira Glaciation left moraines about 2 km down-valley of the site (Soons 1963). The date for N.Z.-1290 poses a serious problem of timing however, and is interpreted here as erroneous

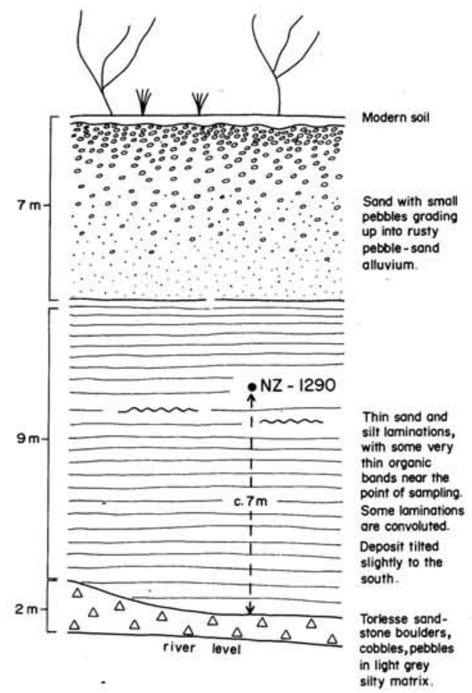

Figure 9. Diagram of section at the lower Acheron River site.

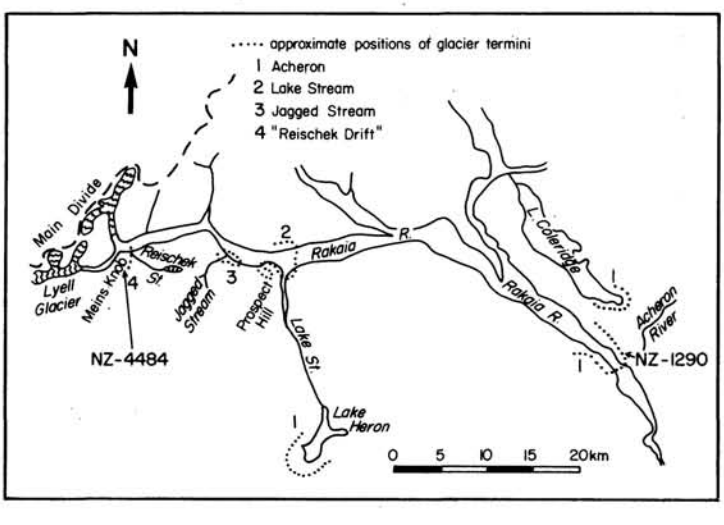

Figure 8. Location map for sites in the Rakaia Valley.

through contamination of the sample by young carbon. A date from sediment near the bottom of a mire at Prospect Hill nearly 40 km up-valley, 11,900 $\pm$ 200 yr B.P. (N.Z.-1652) (Burrows & Russell 1975) is a minimal age for recession from the last Otiran stadial in the area. Recession from the final Otiran stadial probably began at least 2,000 years earlier (based on the date 13,750 $\pm$ 200 yr B.P., (N.Z.-5287) a minimal age for recession from the last Otiran stadial in the Waimakariri Valley, the next catchment to the north (Burrows 1983)).

2. *Meins Knob, Upper Rakaia Valley.* Burrows & Russell (1975) described the moraines of the upper Rakaia Valley, and their relative chronology. During subsequent field work a sample was obtained from the bottom of a peat deposit on the summit of Meins Knob (Figs. 8 & 10). The date (N.Z.-4484, 9,480 $\pm$ 130), is a minimal age for recession of the enlarged Lyell Glacier after its extension across the top of Meins Knob into the Reischek Valley. At this time the glacier surface, at its highest, was more than 300 m above the present Lyell Valley floor. Undifferentiated till (the 'Reischek Drift' of Burrows & Russell 1975) and recessional moraines were deposited by the glacier tongue in the lower Reischek Valley and on the east side of the Meins Knob ridge. Meltwater streams flowed from the glacier as it receded, cutting channels in bedrock.

The glacier expansion which gave rise to the 'Reischek Drift' and recessional moraines seems to have been a distinct glacial readvance pulse, subsequent to a larger glacial episode which deposited the Lake Stream moraine at Prospect Hill, about 18 km down-valley (Fig. 8) (Burrows & Russell 1975). The date from Meins Knob shows that the later advance phase was over before 9,480 $\pm$ 130 yr B.P.

The relatively small Jagged Stream moraine (Fig. 8) was thought by Burrows & Russell (1987) to represent a glacier readvance episode which filled the whole Rakaia Valley not long after the Lake Stream advance. After reinvestigation of the Jagged Stream moraine with P. Birkeland, it is now proposed that, during a distinct glacial episode, a small glacier tongue flowed down the Jagged Valley and turned downstream as it entered the Rakaia Valley, leaving the Jagged Stream moraine close to the valley wall.

The Jagged Stream and 'Reischek Drift' glacial episodes may have been contemporaneous. Both postdate the Lake Stream advance, and recession from them may have occurred by about 10,000 yr B.P. Organic layers below and above a band of inorganic sediment in Quagmire Tarn on Prospect Hill, outside the limit of the Lake Stream moraine, were dated 11,900 $\pm$ 200 yr B.P. (N.Z.-1652) and 10,000 $\pm$ 150 yr B.P. (N.Z. -1653), respectively (Burrows & Russell 1975). A reasonable inference is that the inorganic layer in Quagmire Tarn began to accumulate with the onset of the Lake Stream event, about 11,900 yr B.P., and its accumulation ceased when the 'Reischek Drift' - Jagged Stream event ended about 10,000 yr B.P.

This upper Rakaia evidence hints at considerable climatic fluctuation during the time from the end of the last Otiran stadial until about 9,000 yr B.P. (cf Burrows and Gellatly 1982). Further investigation of the detailed chronology of events is needed.

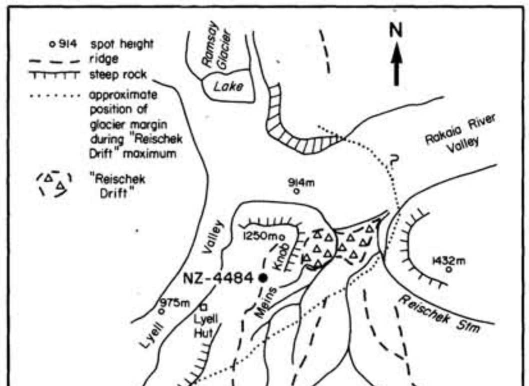

Figure 10. Map of the Meins Knob area showing features mentioned in the text.

Rangitata Valley, Central Canterbury

1. *Craig Phillips Moraine, Mt Potts Station.* Sediment from a deep mire in moraine at the

south-east end of the roche moutonee Craig Phillips (Fig. 11) provides a minimal age of 11,450 ± 350 yr B.P. (N.Z.-6288) for recession of ice from the final stadial of the Otira Glaciation, which left moraines further east near Lake Clearwater and Hakatere Station homestead (Mabin 1980). The date is about 2,500 years younger than expected (based on the Waimakariri evidence (Burrows 1983)).

Alternative interpretations of the date are either that organic sedimentation began relatively late in the Craig Phillips mire, or that the deepest part of the mire was not sampled. Less likely is the suggestion that the Rangitata Glacier shrank back from its last Otiran stadial extent more than 2,000 years later than the Waimakariri Glacier. Further investigation of the Craig Phillips site is warranted.

2. *Sinclair Plateau, Upper Clyde Valley.* A prominent lateral moraine occurs on the northern side of the Sinclair Plateau, and till deposited by the glacier which formed the moraine, mantles the Plateau surface (Fig. 11). The date N.Z.-4772, 9,730 ± 190 yr B.P., for a sample from the bottom of a mire beside a tarn on the Plateau, is a minimal age for recession of the Clyde Glacier from the advance which deposited the moraine.

On the grounds that each is the largest post-Otiran moraine, and that they occur in comparable positions in their respective valleys, the Sinclair Plateau moraine is correlated with the Lake Stream moraine in the Rakaia Valley, the Wildman I moraine in the Cameron Valley (older than 9,520 ± 100 yr B.P., N.Z.-688, (Burrows 1975)) and the Birch Hill moraine in the Tasman Valley, Canterbury. Similar large features in the other tributaries of the Rangitata River are the Hells Gates moraine in the Lawrence Valley and the Mistake Plateau moraine in the Havelock Valley. In turn, all of these moraines are correlated with the Waiho Loop moraine of the Franz Josef Glacier in Westland. Dates of wood for the glacial advance which formed the Waiho Loop moraine have recently been discussed by Mercer (1988). Those from the New Zealand D.S.I.R. laboratory are: 11,450 ± 200 yr B.P., N.Z.-4234 (Wardle 1978); 11,500 ± 200 yr B.P., N.Z.-6573; 11,700 ± 200, N.Z.-6923 (Mercer, 1988). These samples all received minimal pretreatment. Those from laboratories in the U.S.A. done on portions of the same log as N.Z.-6923 and N.Z.-6573, but where the samples were pretreated with HCl and NaOH, are: 12,100 ± 275, GX-10053 and 12,510 ± 120, Beta-12607 (Mercer, 1988).

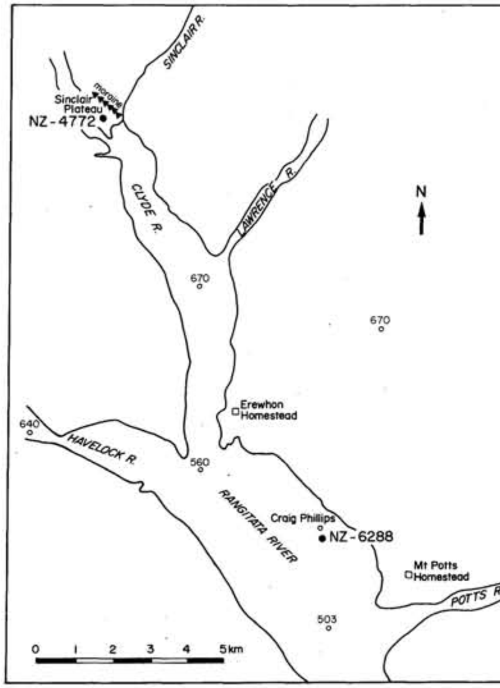

Figure 11. Location map for sites in the Rangitata Valley.

FIORDLAND

Takahe Valley, Lake Te Anau

Bogs with relatively shallow peat cover the floor and gently-sloping sides of Takahe Valley, Fiordland (Fig. 12). A peat sample taken by coring the deepest of these bogs gave a date of 11,300 ± 200 yr B.P. (N.Z.-5530). Apart from showing that the valley was deglaciated prior to 11,300 yr B.P., the date indicates the beginning of organic sedimentation there.

DISCUSSION

Although the numbers of radiocarbon dates for Otiran and early Aranuian glacial episodes is slowly increasing, we still lack material for a definitive chronology of glacial events in New Zealand in the period 20,000 to 9,000 yr B.P. (Burrows & Gellatly 1982, Burrows 1983, 1984).

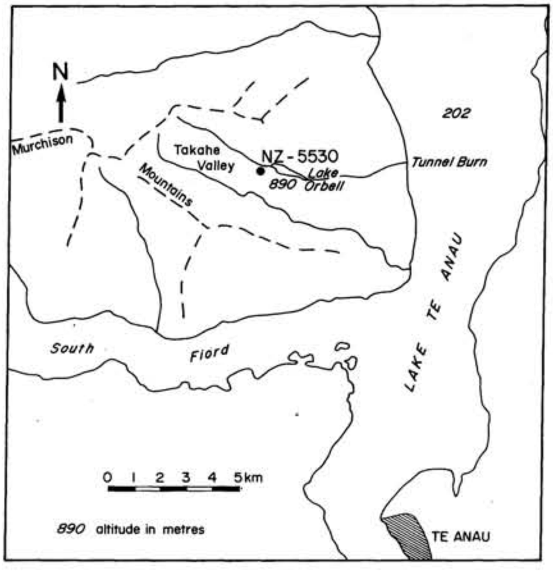

Figure 12. Location map for the Takahe Valley site.

The uncertainty about the chronology arises from uncertainty about stratigraphic context, as well as the different manifestations of glacial events in different localities (Burrows 1984) and the various problems of interpretation of radiocarbon dates. Some of these problems, inherent in terrestrial deposits, may be solved by pollen and other analyses of continuous sedimentary cores taken from the seabed in appropriate places off the New Zealand coast, especially if tephras are present to provide clear marker horizons. The sediment, fossil and oxygen-isotope studies of Nelson *et al.* (1985), from a deep sea drilling-site east of the South Island are useful contributions in this direction.

Contamination of radiocarbon date samples by young (or old) carbon is a possibility frequently ignored by Quaternary investigators in this country. In the present instance an attempt is made, using the best available evidence, to account for apparent discrepancies in some of the dates. The question of doubt about the validity of *any* radiocarbon date can be raised. Resampling and stringent pretreatment of the samples to remove possible contaminants, such as young humic acid or old carbonate, before redating is an option which may solve some of the difficulties outlined in the text. Very careful consideration of all possible causes of contamination and standard approaches to pretreatment are strongly recommended for radiocarbon dating in the future.

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